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The agroecological transition of agricultural systems in the Global South

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Chapter 11

From natural regulation processes to technical innovation, what agroecological solutions for the countries of the Global South?

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Agriculture today is faced with new challenges on a global scale: climate change, loss of biodiversity, increasing scarcity of arable land, and exhaustion of resources. The significant increase in productivity over the past 50 years in the countries of the Global North has resulted in large-scale use of fossil fuels and chemical inputs, and has led to a significant negative impact on the environment. Moreover, the substantial and ever-increasing use of pesticides is leading to deteriorating water quality and proven adverse impacts on the health of agricultural workers and consumers.

Agroecology has emerged within this context despite the fact that its development is still caught up in strong societal debates. It is, at the same time, a scientific discipline, a social movement and a set of agronomic practices (Wezel *et al.*, 2009). Irrespective of the definition selected (the political dimension remains a controversial subject), most of the authors who study it agree on a number of biological principles that must guide the functioning of agrosystems. Agroecology is thus based on a core principle: the use of natural processes, often associated with biodiversity, to ensure ecosystem services, including agricultural production. This emphasis on natural processes requires profound changes in current technical systems. These modifications also entail a radical change in the objectives and modalities of agronomic research, one of which, in addition to the development of innovations, is to support actors in their trajectories of technological change.

The aim of this chapter is to identify the scientific knowledge underpinning the biophysical functioning of innovative agroecological farming systems that are being or have been adopted by farmers at a more or less large scale, or which forms the basis of innovations initiated by farmers. While the agroecological movement concerns agriculture in the countries of the Global North as well as in the Global South, our focus in this chapter is on small-scale farmers. Indeed, the situation of small-scale family farming in the countries of the Global South remains unique: most often it remains untouched by the technological revolution, and its sustainability is often based on biological regulatory mechanisms within agrosystems. We will attempt to identify these mechanisms since such agricultural systems can serve as examples in many cases. Local or traditional knowledge can indeed form the basis of sustainable solutions for crop protection and resilience to climate change, since they preserve biodiversity and rely on natural regulatory processes.

In most cases, it is not easy to convince conventional farmers to adopt agroecological practices. Indeed, this new farming method frequently entails major changes in cropping systems, which could be construed as risks by these farmers. For example, there is some reluctance to move away from an intensive system that uses significant amounts of pesticides to an integrated crop protection system or from a system of integrated protection to agroecological protection of crops.

While we must continue to produce scientific knowledge and take advantage of it, it is not the only source of innovation in agroecology. Innovation relies on the ability of actors to mobilize knowledge from various sources and, based on it, to work together to create new knowledge through organized interactions on challenges, constraints and opportunities faced by farmers and societies. While research occupies a key place in the development of innovations, it needs to be recast in the new agroecological context. The examples provided in this chapter are part of this perspective: to provide the most generic knowledge possible to help co-design innovative agroecological systems that represent a sustainable alternative to conventional agriculture.

Concepts and principles for an agroecological agriculture

Natural ecosystems, agrosystems and agroecology

Natural ecosystems often share common characteristics: a high level of biodiversity, permanent soil cover, the presence of woody species, numerous inter-species interactions, etc. In contrast, intensive agrosystems have systematically eliminated these characteristics: drastic reduction in biodiversity (down to a single plant species in the cultivated field), deep and frequent tillage, removal of woody species, and reduced species interactions.

While agrosystems most often consist of a very limited number of cultivated species, natural ecosystems enjoy a rich biological diversity which provides a large number of ecosystem services. Consequently, the agroecological approach is based on a key hypothesis: it is possible to produce sustainably by relying on ecosystem functionalities and by reinforcing biological regulatory processes that result from biodiversity. The approach therefore consists mainly in introducing – or reintroducing – and managing a functional, cultivated and associated biodiversity into intensive agrosystems (which formerly relied heavily on chemical inputs) in order to take advantage of this introduction or reintroduction in terms of ecosystem services.

This approach can be implemented at several scales, from the field to the landscape. As demonstrated in practice, the introduction of biodiversity has significant implications for the functioning of an agrosystem (Malézieux, 2012). Depending on the species and implementation methods selected, it allows more specifically:
– to use the complementarity of functional traits between different species for a better utilization of resources, and thus increase the cultivated ecosystem's total productivity;
– to ensure a permanent presence of soil cover or even tree cover;
– to increase heterogeneity and thus interactions within the system;
– to promote natural regulation of pests and diseases within food webs;
– to use the properties of plants for pest and disease control (attractive and repellent natural substances).

Incorporating a greater plant diversity in space and over time also increases soil organic matter content and improves the biological functioning of soils. Increasing plant diversity is thus crucial to designing agroecological cropping systems (Malézieux *et al.*, 2009). However, there is no simple solution that can be implemented to manage biodiversity. Indeed, only groups of appropriate species, accompanied by a management favouring all the regulatory mechanisms, make it possible to obtain these benefits and increase production, leading ultimately to more sustainable agrosystems. Figure 11.1 endeavours to summarize all the relationships between objectives, processes and innovations in agroecological systems.

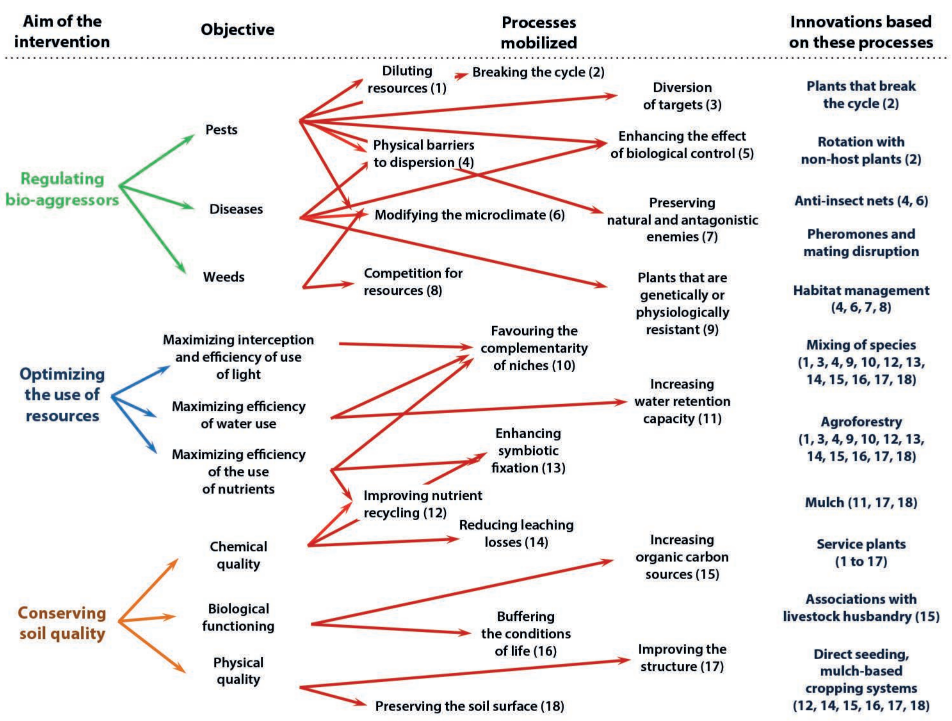

Figure 11.1. Concepts and processes used in agroecology with the aim of reducing the use of chemical inputs (based on Ratnadass *et al.*, 2012; Husson *et al.*, 2015).

The recourse to ecological concepts

As its etymology suggests, agroecology uses concepts from two disciplines: agronomy and ecology. The concepts of ecological niche, species dispersion, biological interaction, community dynamics, multi-trophic interactions, functional redundancy and complementarity are, for example, essential for creating agroecological systems. While these ecological concepts help better understand the functioning of natural ecosystems, their application in agriculture is one of the scientific challenges of agroecology. Examples illustrate how these concepts can be used to design more sustainable agrosystems. Functional complementarity is, for example, an essential element of species association: the association of two species is based on the principle that individuals of one species will be less in competition with those of another species than with individuals of their own species. In ecology, the ability of plants to perform the functions necessary for the survival of the ecosystem is represented by functional traits. This approach has also been recently used in agronomy to study some crop associations (Damour *et al.*, 2018). Aboveground functional complementarity makes it possible to control, or even optimize, the utilization and recycling of resources (see Box 11.1). Functional complementarity has also been mobilized for root systems in order to promote the use of different niches by species with opposing strategies for acquisition, conservation and use of resources (Weemstra *et al.*, 2016).

Plant diversity and control of pests and diseases

By integrating new plant species into the agroecosystem, it is possible to mitigate the impact of insect pests and diseases through several methods which can also be combined (Figure 11.1):

– by using the dilution of resources and diversion phenomena in insects, based on visual and olfactory effects of plants (in-figure nos. 1 and 3);
– by disrupting the pest's life cycle in space using non-host effects (2 and 3);
– by encouraging dynamic allelopathic effects in the soil;
– by promoting specific enemies of the pests and diseases present in the soil;
– by increasing the plant's physiological resistance through an optimized supply of nutrients in the cropping system;
– by stimulating pest control effects through the predation of plant pests, by conserving their natural enemies (7);
– by modifying the architecture of plants to create physical barriers and a microclimate unfavourable to these pests and diseases (4 and 6).

The aim of pest control through 'conservation' is to promote the presence of natural enemies (7). It involves taking the interactions between insects and their natural or cultivated habitats into account in order to then shape these habitats to increase the effectiveness of biological control. These new practices often aim to optimize the conservation of natural enemies in a given area, including in the agricultural plot (Box 11.2; Landis *et al.*, 2000; Altieri and Nicholls, 2004). This requires a knowledge of all the key elements of the landscape surrounding the agricultural plot or farm: the natural vegetation, its location, its characteristics, its size and the plant species present, the fallows, the hedges, the groves, etc. This approach can well be combined with 'traditional biological pest control by augmentation or acclimation of natural enemies of such parasitoids', which favours their artificial introduction in the target agrosystem.

Box 11.1. The association of coffee and erythrina

B. Rapidel

The commonly practised intercropping of coffee and erythrina (*Erythrina* spp.) is a good example of the functional complementarity between species: while erythrina exhibits a strategy of rapid growth, low reserves and induces a very rapid litter decomposition, the coffee plant exhibits a completely different behaviour (in terms of Leaf Economic Spectrum) (Wright *et al.*, 2004), with a dense and decay-resistant wood, and a low specific leaf area (SLA) (Photo 11.1). Furthermore, coffee production is highly dependent on the availability of nitrogen, while erythrina is a nitrogen-fixing legume. The coffee plant is an undergrowth shrub and is adapted to shade environments. While the roots of these two species also exhibit different traits (slow growth and high exploration density for coffee, rapid growth and exploration of a large area for erythrina), they explore relatively similar niches. Thus, these species may compete for water, but since erythrina is much less drought-resistant than coffee, it cannot survive in environments where water availability may be a limiting factor for coffee cultivation.

Photo 11.1. Intercropping of coffee and erythrina. © Bruno Rapidel/CIRAD.

Box 11.2. Push-pull processes in sugarcane cultivation

F.-R. Goebel

Research has identified service plants that can be used or introduced on the border of sugarcane fields in South Africa to boost the natural regulation of the African stalk borer *Eldana saccharina*: wild plants such as *Cyperus*, *Erianthus*, *Pennisetum* or *Desmodium*, and cultivated crops like maize or sorghum, act as parasitoid-attracting or pest-repellent plants (Conlong and Rutherford, 2009; Cockburn *et al.*, 2014). The aim is to increase natural pest control by enriching the biodiversity of sugarcane cropping systems that are often intensive and which have consequently decreased natural pest control (Figure 11.2).

In Réunion, *Erianthus*, a plant similar to sugarcane but which is more attractive to the moth borer *Chilo sacchariphagus*, was tested and used as a trap crop on the border of the sugarcane field to attract and kill this pest (Nibouche *et al.*, 2012). This action can be combined with the release of complementary parasitoids, such as trichogramma, to suppress egg laying by this borer on the border of the sugarcane fields. These service plants can thus be used to develop a push-pull system, which can become a useful part of agroecological crop protection (Goebel *et al.*, 2018).

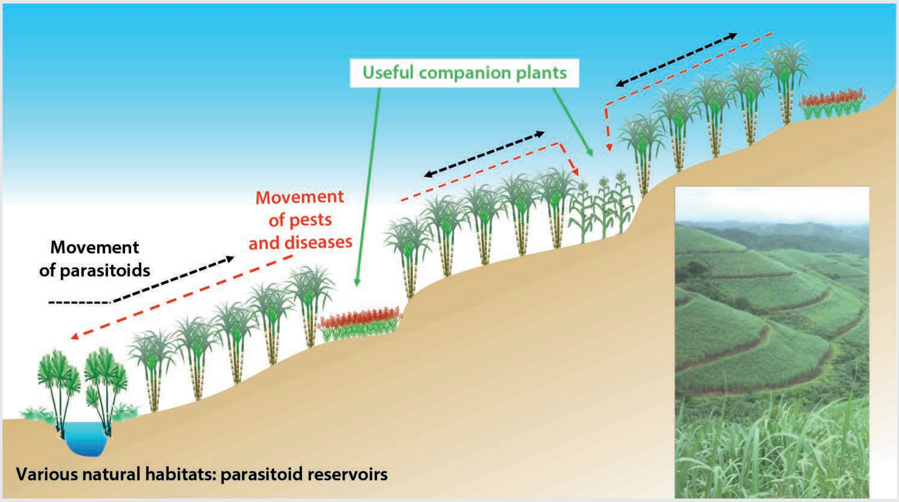

Figure 11.2. Use of landscape elements and introduction of service plants for biological pest control (case of *Eldana saccharina*, a sugarcane pest, in South Africa, Conlong and Rutherford, 2010).

Pest management is based on a broad and in-depth knowledge of interactions in the agroecosystem between insects and their natural enemies (parasitoids, pathogens, predators, etc.), host plants and the natural vegetation that shelters them.

The modification of biogeochemical cycles

The introduction of biodiversity into an agrosystem also affects biogeochemical cycles: water and carbon cycles can become greatly modified (Figure 11.1), in particular by the introduction of woody species, as shown by the agroforestry example in Sudano-Sahelian Africa (Box 11.3).

Box 11.3. Agroforestry in Sudano-Sahelian Africa

B. Rapidel

There are many examples of agroforestry in Sahelian and Sudano-Sahelian Africa. It is, however, often difficult to differentiate between biological and socio-economic reasons to explain the coexistence of trees and crops. Nonetheless, two examples are based on biological foundations which have been studied in depth: the first is the association between crops and the leguminous tree *Faidherbia albida*. This tree characteristically loses its leaves in the rainy season, thus enabling the maintenance of a high level of soil organic matter (a common role of trees in agricultural systems) while not competing for light and water with rainy season crops. Its fast-growing root system allows this species to reach the water table in its early years of growth, and thus maintain its leaves in the dry season (Roupsard *et al.*, 1999). These leaves are harvested based on demand and provide supplementary feed for livestock. This species has been widely used in reforestation programmes in Niger (Garrity *et al.*, 2010). The second example is of the dry-area shrubs *Guiera senegalensis* (Combretacea) and *Piliostigma reticulatum* (Fabacea), grown in the Sahelian area in sorghum and millet fields. These shrubs have deep roots and maintain their foliage in the dry season by capturing water resources inaccessible to the annual cereals with which they are intercropped (Louppe, 1991). Research studies have shown that their root systems redistribute water to shallow horizons from deeper wetter horizons (Kizito *et al.*, 2012). They can also withstand an almost total annual pruning. They are frequently cited as a restoration species for degraded soils because they promote an accumulation of organic matter (Diack *et al.*, 2000).

From ecological principles to innovation

Agroecological principles must be translated into concrete achievements that are implemented by actors at the scale of the plot and cropping system. The questions the agronomist has to ask in order to do so are: Which species to associate? What operational methods to adopt? How to design these new and more complex systems? How to evaluate them? Based on what criteria?

We thus move from the principles of agroecology to innovations based on modalities of action. The principle of introducing biodiversity into an agrosystem may include different modalities of action that stimulate identified agroecological processes (see Figure 11.1). These mainly involve combining organisms (Malézieux *et al.*, 2009): we can combine varieties as well as productive plant species, introduce service plants, and combine non-woody and woody species as well as plant and animal species (see Figure 11.2). Each of these practices initiates several processes. The more the number of possible theoretical combinations, the more difficult the search for efficient systems becomes. Moreover, among the efficient systems, those the farmers find acceptable are even more limited. In addition to the spatial dimension, the temporal dimension is essential: rotations, whether in association with cover species or not, represent an essential agroecological modality of action. The time step can be very variable: to the short time span of the association of vegetable species whose cycle lasts only a few months, we associate woody species whose cropping period lasts several decades. These two time spans can interact perfectly: the farmer must manage both time steps, sometimes on the same plot. It is thus possible to establish a typology of cropping systems based on an increasing complexity of systems and the introduction of woody species.

In the following sections, we will illustrate these different modalities of introducing biodiversity through four successive case studies: service plants in monocultures, mulch-based cropping systems, intercropping of two woody species, and complex systems in humid tropical regions.

A key agroecological example: service plants and weed management

The diversity of communities present in agrosystems is likely to assist the provision of a number of ecosystem services. The control of weeds (i.e. plants causing loss of yield by competing with the cultivated crop) is, for example, directly linked to the plant biodiversity existing in plots. The introduction of a service plant is thus a way of modifying the composition of the plant community in order to promote this service. In our weed control example, choosing the species of the service plant is complicated as it can lead to competition with the primary crop. Service plants must satisfy a set of characteristics, some of which may be contradictory (Figure 11.3).

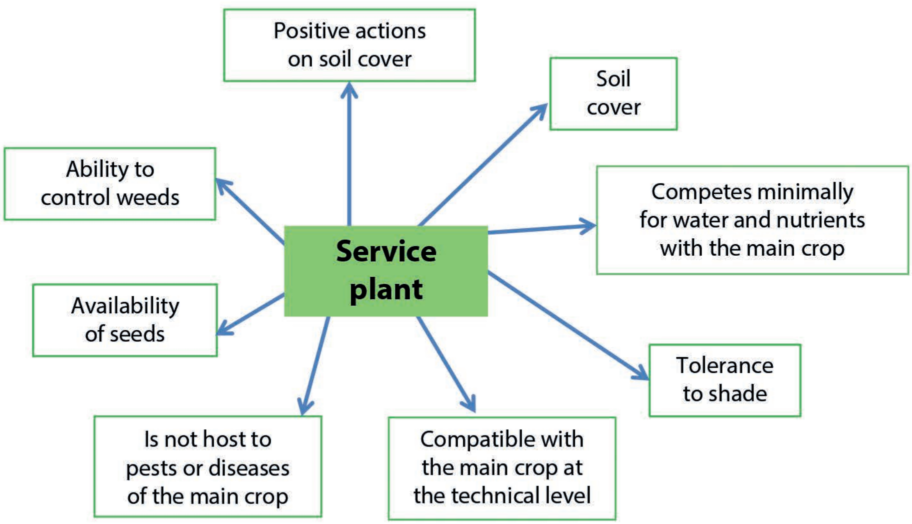

Figure 11.3. The set of services that service plants must be provide.

In general, service plants are capable of providing multiple ecosystem services through the modifications they make to the environment, either physical (physical and chemical structure of the soil) or biological (see Figure 11.1). They are thus increasingly used, for example, in various cropping systems such as banana plantations and orchards to control weeds, and eventually limit herbicide use (Boxes 11.4 and 11.5). Furthermore, the inclusion of a cover crop modifies the system's overall functioning in terms of the water and nutrient cycles (Tixier *et al.*, 2011), as well as the interactions between insect and micro-organism communities (Duyck *et al.*, 2009). The addition of a new resource to the system is a strong lever to modify food webs. Be it aboveground or underground, this new resource can help increase the abundance of herbivores, and thus favour an increase in the number of generalist predators who, in turn, are likely to contribute to improved pest control.

Box 11.4. Service plants in banana plantations

P. Tixier

Service plants have been widely used in banana plantations in the French West Indies, either between cropping seasons or in association with the banana trees. These two options require plants with potentially different characteristics. During the between-crops period (grass fallow), in addition to having a very good ability to cover the soil and control weeds, a service plant suitable for fallows must:
– not be host to plant-parasitic nematodes of banana trees (*Radopholus similis* and *Pratylenchus coffeae*) so that the fallow period fulfils its role;
– improve the physical structure of the soil (organic tillage);
– be compatible with the replanting of banana trees at the end of the fallow period and ensure nutrient restoration following the planting of banana.

The characteristics of service plants associated with the banana tree should be within a narrow range that allows good weed control without competing for resources with it. The service plants must also be flexible enough to adapt to variations in the light resource available during production cycles (closure of the canopy in the first cycle, reopening after harvests). One method for selecting service plants is based on describing the functional traits of potential species as (easily measurable) evaluators of the services they are likely to provide (Damour *et al.*, 2014). To implement this approach, a large number of species had to be collected and characterized, followed by testing of the most promising ones in prototype cropping systems. These steps make it possible to validate the selection by taking into account the technical constraints and by making adjustments to the management of the cover crop.

The addition of a cover crop also helps support a richer food web (predators and omnivores) (Djigal *et al.*, 2012). However, the effect on pest and disease control often depends on the species of the cover plant. Thus, plants of the Poaceae family seem more suited to regulate plant parasitic nematodes than those of the leguminous family. The situation is similar above ground where generalist predators (mainly the ant *Solenopsis geminata*) are more abundant in plots with a cover crop (*Brachiaria decumbens*) than in plots with bare soil (Mollot *et al.*, 2012).

Service plants are also used within annual crops. Annual species are associated using numerous techniques including mulch-based cropping systems. The aim of the direct seeding mulch-based cropping system, a practice linked to conservation agriculture, is to maintain a permanent plant cover and limit tillage only to sowing furrows. This practice reduces erosion and enhances soil biological activity, contributing to the sustainable management of soil organic matter. Direct seeding mulch-based cropping systems have been adopted in many tropical regions (mainly in Africa, South America, Southeast Asia) as well as in France. In the case of rice cultivation in Madagascar, the first trials of direct seeding mulch-based cropping systems date back to the early 1990s. The mulch cover presents several benefits during the cultivation of rainfed rice: it provides a large amount of organic matter, limits direct evaporation from the soil, reduces temperature variations on the soil surface, and has a strong effect on weeds, which results in an increase in yield at the end of the cycle (Ranaivoson *et al.*, 2017) For example, the use of the perennial legume *Stylosanthes guianensis* (Fabaceae) as a cover crop, which produces a high biomass and has allelopathic effects on soil pests like white grubs and even some nematodes, has been proven to be successful (Husson *et al.*, 2013; Husson *et al.*, 2015).

A direct seeding mulch-based cropping system, based on a biennial cereal-cotton rotation, was proposed in the cotton basin of Cameroon after four years of conclusive experimentation (Naudin *et al.*, 2010). In the first year, a cereal (sorghum or maize) is associated with a grass (*Brachiaria ruziziensis*) or a legume (*Crotalaria retusa*) cover crop. The objective is to maintain the cereal yield, the staple family diet, while producing enough biomass to cover the soil after the harvest. Cotton is sown manually the following year in the dead plant cover. Farmers have adopted this system and development agencies have recommended its use.

Box 11.5. Management of natural weed growth in orchards

F. Le Bellec

Citrus fruits are often attacked by various pests and diseases that affect crop quality and the lifespan of the trees in the case of certain diseases. The phytophagous mites and some insects (such as thrips) cause irreversible damage to the fruits when their populations outbreak. Farmers adopt various preventive phytosanitary measures to limit such damage. Mites of the Phytoseiidae family can help regulate the populations of phytophagous mites and thrips. However, phytosanitary protection applied on the latter necessarily impacts the former. It is possible to promote a suitable habitat for Phytoseiid populations in such orchards through a sound management in space and time of natural weed growth in citrus orchards (Photo 11.2).

Studies have thus been carried out in orchards in Réunion (Rothé *et al.*, 2016; Simon *et al.*, 2017). The floristic diversity of the weed cover in these orchards – regardless of the weed management method – ensures an abundance of functional traits leading to a diversity and abundance of habitat and food for generalist predators (ladybugs and Phytoseiidae). Thirteen Phytoseiidae species have been found in the weed cover in these orchards.

Maintaining an almost undisturbed habitat within an orchard can thus potentially increase the effectiveness of biological control while reducing pesticide use. But how can the functional biodiversity within these orchards be increased in order to promote the ecosystem service of pest and disease control? The study of functional traits of species of the spontaneous flora helped predict the composition of different weeds within the natural growth for various management methods, and thus suppress or favour certain plant species in these communities. Nevertheless, in order to ensure the perpetuation of the pest control ecosystem service, the management strategies used must create transitional refuge habitats for auxiliaries. This requires the differentiation over time and space of various weed management interventions. These techniques are thus complex and require a good knowledge of the processes to be implemented.

Photo 11.2. Weed management in citrus orchards. © Fabrice Le Bellec/CIRAD.

Agroforestry systems

Agroforestry systems are cultivated systems that combine several layers (at least one tree layer combined with one herbaceous layer) and which often have a high specific diversity. Agroforestry systems, situated in between the cultivated field and the forest (*ager* and *sylva*), combine annual and perennial herbaceous and woody species, as part of a set of more or less complex practices. Agroforestry systems are not specific to the tropics: they were very common in temperate and Mediterranean areas before the introduction of mechanization, and are currently experiencing a revival. In the tropics, they are very prevalent in many small family farms and the international scientific community is showing an increasing interest in them.

The association of two woody species

The most widespread examples of agroforestry in the world are in fact represented by the associations of perennial plants, i.e. the cultivation of perennial crops (mainly cocoa, coffee, rubber, coconut) in association with other perennial species. There are two broad types of associations: existing shade trees from thinned forests with inter-cropping of the perennial crop – i.e. agroforests – or specific planting of shade trees at the time of, or slightly before, planting the perennial crop in the plot. The specific diversity of shade trees is generally lower when they are planted on bare land.

Two perennial crops can also be cultivated in association. Such associations are made possible by the shade tolerance of some crops, such as coffee and cocoa, that grow from the understory. In other cases, however, these associations take advantage of the delay between the planting of the perennial crop and its entry into production, and the time required by certain perennial crops to occupy the plantation area. For example, there are coffee plantations that come into production three years after planting, with rubber trees in inter-rows that starts production six to seven years after planting. In most cases, agroforestry promotes the provision of several ecosystem services (Box 11.6).

Complex agroforestry systems in humid tropical areas

Based on a multi-layered tropical forest model, agroforestry systems in the humid and sub-humid tropics provide local livelihoods and fulfil key environmental and socio-economic functions. Agroforestry systems in humid regions are characterized by a rich and planned biological diversity (the farmer manages a large number of plant species in a planned manner), a high structural heterogeneity of the system, a significant evolution of the vegetation structure over the long term, and the provision of numerous ecosystem services. They offer are a good example of sustainability based on the role of biodiversity (Box 11.7).

How to turn agroecological principles into action?

Agroecological principles are based on analysing the functioning of natural ecosystems. For scales larger than that of the plot, several levels of organization have to be understood in order to implement these principles in agrosystems. Thus, the agroecological approach must first be implemented at the farm level (choice of species, plant-animal interactions, organization of crops within the farm's production areas and in its agricultural calendar, maintenance of biodiversity islands, etc.). More broadly, the scale of the watershed must also be considered, as also that of the landscape (i.e. landscape ecology), mainly in order to take into account the regulations specific to territory-wide interactions and the habitats of different pest and auxiliary species. But the agroecological approach must also be integrated into the more or less territorialized social systems that make up agri-chains and, more generally, into food systems (Figure 11.5).

Box 11.6. Coffee-based agroforestry and the provision of ecosystem services

B. Rapidel

The association of coffee with trees provides ecosystem services to farmers and to society, but these services are generally not taken into account (Rapidel *et al.*, 2011) (Figure 11.4 and Photo 11.3). Following the classification proposed by the Millennium Ecosystem Assessment (2005), we can list the different services provided by plantations in Central America.

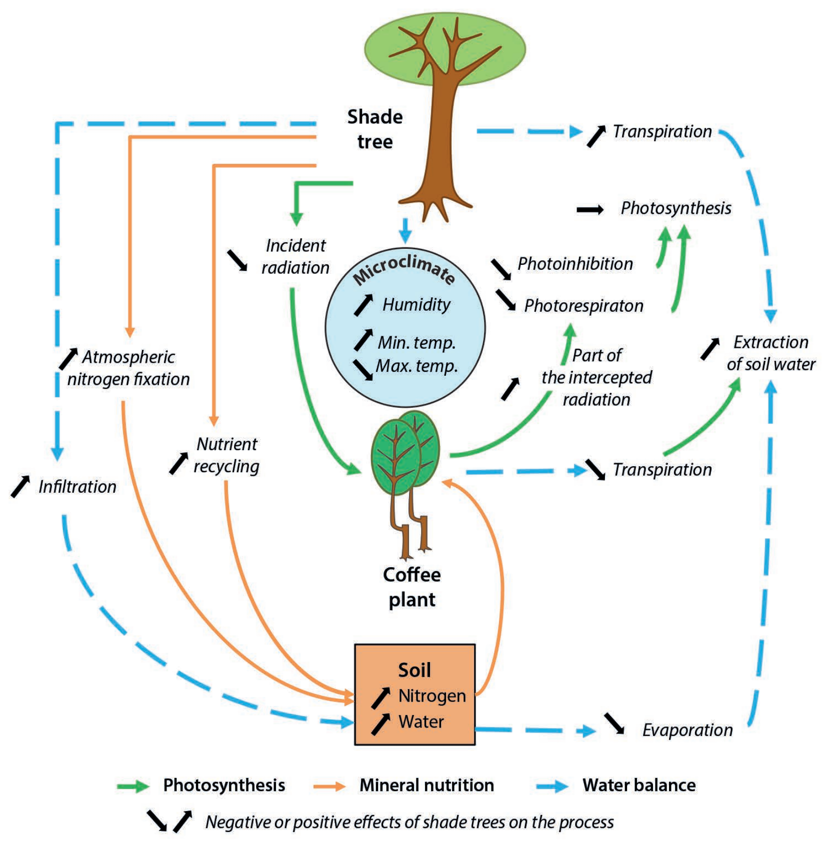

Figure 11.4. Effects of shade trees on photosynthesis, water balance and nutrient uptake of coffee plants (Rapidel *et al.*, 2015).

Provisioning services

It has been shown that simplified agroforestry coffee plantations producing bananas, for example, lead to a better quality diet (Meylan *et al.*, 2013). In more diverse systems, various additional products represent significant additional sources of income. These systems, which have a permanent ground cover, protect the soil surface with decomposing residues, and supply better quality, less sediment-laden water to downstream dams.

Regulating services

These plantations help regulate climate, with better greenhouse gas balances due to the reduced use of synthetic fertilizers (Hergoualc'h *et al.,* 2012). They help control pests, for example by birds controlling the coffee borer, but more generally by enriching aboveground and underground food webs. These regulating services, however, depend on the pests and diseases concerned. Indeed, microclimatic conditions under the shade of trees can, in particular, be favourable to some fungal diseases.

Supporting services

While nutrient recycling has improved in these plantations (a fact that has been widely observed), symbiotic nitrogen fixation (Meylan *et al.*, 2017) and the conservation of soil fertility have also seen an improvement.

Finally, the positive effect of agroforestry systems on the conservation of plant and animal biodiversity has also been positively established on numerous occasions (De Clerck *et al.*, 2010). It is relatively clear that these systems are preferable to plantations that are fully exposed to the sun, especially when such capabilities to provide services are combined in agroforestry systems that are co-designed with farmers (Meylan, 2012). These services can thus provide farmers with higher incomes. However, this is not always the case, especially when the only product valued monetarily is coffee, the production of which, depending on the case, may be lower in an agroforestry system.

Photo 11.3. Coffee plants under shade. © Bruno Rapidel/CIRAD

Box 11.7. Agroforestry systems in humid areas

É. Malézieux

Some coffee and cocoa agroforestry plantations in Central America, Asia, and Africa reproduce the structure of natural forests and thus have biodiversity indices that are often comparable to protected forests, thus representing a significant conservation value (Deheuvels *et al.*, 2012) (Photo 11.4). A high diversity of cultivated or naturally growing plants serves as a refuge and habitat for numerous plant and animal species, thus playing a key role in maintaining the original biodiversity in sensitive areas. At the social level, the multiplicity of sources of income or of services (wood, pharmacopoeia, hunting, gathering, climate protection, limitation of nitrate losses, landscape, fire protection, etc.) offered by agroforestry systems is often considered an important factor of stability, as shown by the example of cocoa farms in Cameroon (Jagoret *et al.*, 2014, and Chapter 3). This helps compensate for the volatility of prices of agricultural products (e.g. of tropical crops such as coffee and copra).

Photo 11.4. An agroforestry plot in Cameroon. © Eric Malézieux/CIRAD.

The agroecological approach also raises the issue of the process of innovation. There is some distance to cover, which can be long and arduous, between the generation of scientific knowledge on the functioning of ecosystems and its use to design sustainable agricultural system that can be implemented by farmers. In other words, there exist many steps between the formalization of principles that could form the basis for an 'agroecological' farming system, and their translation into actual large-scale technical systems. In the domain of agroecology, innovation often requires the

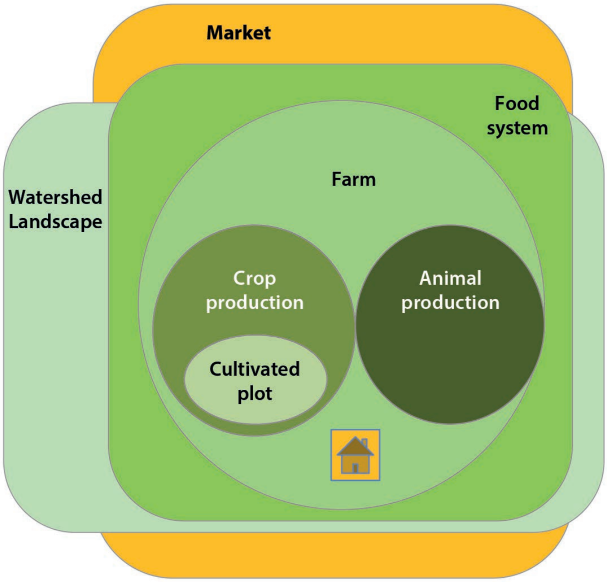

Figure 11.5. Different integration scales (based on Griffon, 2013).

sustainable appropriation and mobilization by farmers of both scientific and local knowledge of processes that are often complex. It also requires a forum for interactions between researchers, development actors and farmers. Several approaches have attempted to formalize these multi-actor innovation processes. Examples include some approaches used for orchards (Le Bellec *et al.*, 2012) and the DATE (Diagnosis, Design, Assessment, Training and Extension) approach, which can be used not only to co-design innovative farming systems in conservation agriculture but also to undertake multi-criteria evaluations (Husson *et al.*, 2015). This latter multi-scale participatory approach brings together several partners and integrates scientific and local knowledge. In general, the implementation of the agroecology paradigm requires the research community to integrate these new elements and to be able to implement them in a broader context for development actors and civil society. Consequently, a key element in the development of agroecology around the world is the adoption of appropriate public policies.

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